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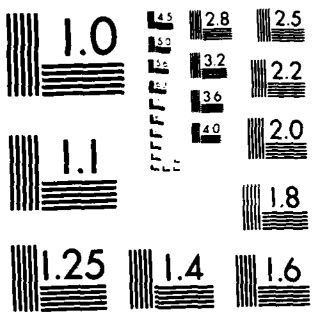
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FOREIGN TECHNOLOGY DIVISION

SLIP FORMS FOR THE CONSTRUCTION OF PRESSED CAST-IN-SITU
CONCRETE LININGS FOR SHIELD TUNNELING

by

F.T. Skuybin, Ye.F. Dushenko, V.N. Korol'kov

EDITED TRANSLATION

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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Slip Forms for the Construction of Pressed Cast-In-Situ Concrete Linings for Shield Tunneling

F. T. Skuybin, Ye. F. Dushenko, V. N. Korol'kov

Pressed cast-in-situ concrete linings have a number of advantages in comparison with precast (the absence of joints, increased strength, and watertightness, the possibility of combining the driving (tunneling) and supporting operations, the carrying out of nonsettling tunneling, which is especially important within the limits of a city, etc.), which make it possible to ensure an increase in the rates and a reduction in the cost of the construction of tunnels.

These advantages have been conducive to the broad introduction of pressed linings in the practice of tunnel-construction under a great range of engineering-and-geological conditions.

In employing linings made from pressed concrete the forces of the shield jacks are employed not only for moving the shield, but also for pressing the mushy concrete poured behind the forms with the simultaneous compression of the water from it.

However, up to the present time there has not been created a reliabledesign of shield complex with pressed linings, the technical-and-economic indices of which would be sufficiently high in comparison with the standard shields, adapted for the construction of precast linings.

Sectional traveling forms are mainly employed for the construction of pressed cast-in-situ linings of tunnels with a diameter of 2 m.

The following deficiencies are inherent to these forms,

1. Operations on the assembly, the disassembly and the moving of massive sections of forms to a new site greatly increase the duration of the driving (tunneling) cycle and the expenditures of labor on the construction of a tunnel.

2. The mechanisms for the execution of the indicated operations encumber the face, and it is necessary to execute all the operations of the tunneling cycle under hindered conditions.

3. With an increase in the diameter of the forms the time spent on moving them increases.

4. The individual rings of the forms, calculated for a pressing pressure of up to 30-40 kg/cm^2, normally operate only in the forming zone. Subsequently these rings, remaining in place and performing the role of a supporting form, operate unpractically with a large reserve of strength and rigidity.

5. During the removal of the forms from the concrete, which has still not accumulated the rated strength (as a result of the process of its adhesion with the material of the forms), in the tunnel lining, breaking tensile stresses can appear, leading to the appearance of cracks and other deformations.

All these deficiencies are the reasons for the slow tunneling rates (not more than 50-60 m per month).

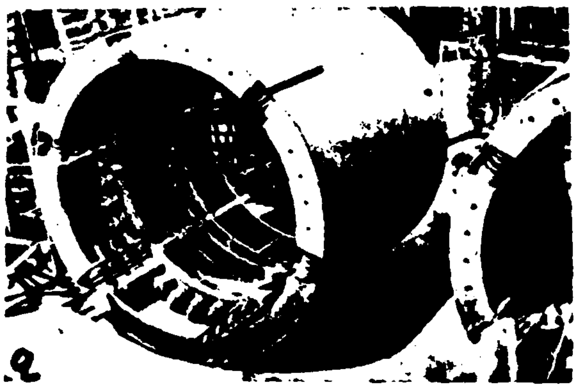
The tunneling rate can be increased by employing slip forms. By moving after the shield in the process of the construction of the lining, the slip forms do not require special special equipment and time for their movement, which makes it possible to carry out continuous concreting. Taking into account the increase in the carrying capacity of the lining along the length of the forms and depending on the rate of their movement it is possible to manufacture the latter (the forms) structurally with different strength values.

The experience in employing rigid slip forms has revealed a number of deficiencies in them. Thus, during the construction of the collector (sewage conduit) with a diameter of 4.6 m in Biryulevo it was established, that rigid slip forms considerably increase the resistance to the movement of the shield. With a pressing pressure of the order of 20 kg/cm^2 the forms got wedged, which led to the breakdown of the concrete lining and to the deformation of the forms during movement.

During the construction of one of the distillation tunnels of the Tbilissi subway with a diameter of 5.1 m the possibility of the employment of slip forms for the construction of pressed cast-in-situ linings of large diameters was checked out. For this purpose one section 1 m long of existing traveling hinge-folding forms with carefully machined external surface was converted with the aid of bolt connections into a rigid nonchanging set of forms and was connected to the shield with six metal rods. For better maneuvering of the shield two hinges each were installed on each rod. The concreting of the lining was carried out in progress cycles 0.5 m longwith a pressing pressure of 10-15 kg/cm^2. During an experiment deformations were measured on its internal surface. Investigations showed, that although the quality of the obtained concrete of the lining is good, the rigid slip forms have a number of significant deficiencies, which impede and even make its utilization impossible.

Of these the absence of pliability of the forms structures is the main one. Since deformations of the forms during the movement of the shield develop nonuniformly, attaining a maximum near the pressing ring and decreasing towards the tail part, then wedging of the forms in the lining occurs with damage to the latter or breaking of the fastening connections. With an increase in the length of the forms the shearing strength increases during their (the forms) breaking away from the concrete. The employment of such forms on curvilinear sections is generally impossible.

For eliminating the indicated deficiencies of rigid slip forms pliable slip forms are being developed and manufactured at the Scientific Research Institute of Foundations and Underground Structures (NII osnovaniy) (Fig. 1)*. The pliability of the forms in the transverse and the longitudinal direction is accomplished by installing spring elements in the joints between the segments and the sections of the forms.



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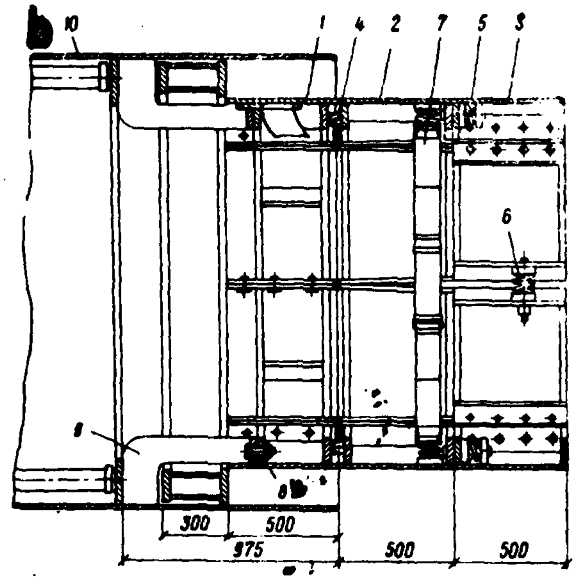

Fig. 1. Overall view (a) and diagram of a pliable slip form.

The forms consist of three main parts: the rigid 1 (first section), the transition 2 (second section) and the pliable (flexible) 3 (third and all the remaining sections).

Within the limits of the first section at the time of the movement of the of the shield the pressing of the concrete mixture takes place. The connection of the segments in it is accomplished on the basis of bolts, which makes it possible to assemble and disassemble them directly in a tunnel. The transition section is connected with the rigid section with hinges 4 and has a pliability (flexibility), increasing linearly along its length, which ensures a smooth transition from the rigid part of the forms to the pliable (flexible) part. The pliability (flexibility) in the longitidunal direction is ensured

* Inventor's certificate No. 264433

by spring elements 5, and in the radial direction - by elements 6. The rigid part of the form is connected by bolts 8 to the brackets 9 of the tail part 10 of the shield. The pliability (flexibility of the forms makes it possible during the movement of the shield to avoid wedging in the formed lining even with a certain decrease in the diameter of the latter, ensuring at the same time the reliable support of the hardening concrete with the aid of spring device 7 and practically eliminating the adhesion forces with the lining and the possibility of the wedging of the forms.

The length of the forms, the number of its sections and the outward thrust forces as was already mentioned, depend on the carrying capacity of the lining and the tunnel building rate. Fig. 2 presents a graph of the dependence of the carrying capacity $p_{o\delta}$ of the lining-forms system on the external load p_{BH}. The carrying capacity of the forms and of its sections is determined by the equation

$$p_{on} \geqslant p_{вн} - p_{об}.$$

The ordinates of the cross-hatched part correspond to the carrying capacity, distributed over the length of the forms, necessary for ensuring its operational efficiency. The intersection of curves $p_{o\delta}$ p_{BH} gives point B, in which the carrying capacity of the lining is equal to the external load, and the cross-hatched part corresponds to the minimum values of the carrying capacity of the forms and the sections over its length.

Taking the safety factor into account, the minimum carrying capacity of the forms should be increased by the magnitude BB'. This, there is determined the entire length of the forms l and the necessary supporting force on each of its sections, where l, in its turn, is the tunnel driving rate function.

The forces in the elastic elements are found depending on the load, exerted on a corresponding supporting section of the forms, and on its design.

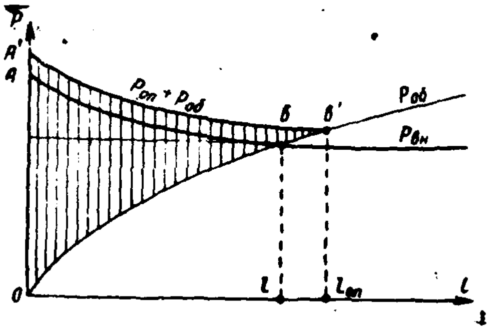

Fig. 2. Graph of the dependence between the external load and the carrying capacity of a lining-forms system.

The necessary degree of pliability (flexibility) and rigidity of the forms, determined by calculation, is attained by the compression of the corresponding spring elements.

The parameters, determining the expressions, going into the equation, presented above, were found experimentally on a special pressing device, distinguished by the disarticulation of the upper wall at the section. Moreover, the pliability (flexibility) of the sections makes it possible to employ the forms on curvilinear tunnel sections.

The operating efficiency of the slip forms depends to a great extent on the correct selection of their parameters. The initial data for the selection of the parameters of traveling forms are a progress cycle for concreting, approximately equal to a two-fold thickness of the lining (0.4-1.0 m), and a maximum pressing pressure for the concrete mixture, reaching 20-30 kg/cm^2 and more.

In calculating the parameters of slip forms it is necessary to take into account the value of the external load and the character of its development in interacting in time with the ever increasing carrying capacity of the lining itself, and also the adhesion of the lining concrete with the forms depending on the hardening time, the coefficient of friction of the metal on the concrete, etc. In this case the support, represented by the forms-lining system, is installed directly behind the shield and is introduced into operation immediately after the pressing of the concrete mixture. In undergoing the effect of an external load, this system should have sufficient carrying capacity, ensuring reliable resistance to the rock pressure (pressure in mining). In this case within the system itself there will occur a constant process of redistribution of the external load between the forms and the lining. The lining, being in a plastic or elastoplastic phase, will have variable deformative characterisitics and its own carrying capacity in time. As a result of this it will receive the ever increasing share of the external load. In connection with such complex interactions, it is not possible to calculate the system by the usual methods without experimental data, obtained under full-scale conditions.

Experiments have shown, that the effect of the age of the concrete on the coefficient of static friction is insignificant and for the calculation it is possible to take its average value, equal to 0.54.

It is evident from Fig. 3, in which the dependence of the coefficient of lateral pressure ξ on the age of the concrete is represented, that the coefficient ξ for a freshly poured concrete mixture is equal to 0.45. The values of sharply decrease with the age of the concrete, and beginning with a one-day's age the curve flattens out, attaining a value of 0.105 by a two-day's age.

Thus, the axial load of pressing creates a perceptible lateral outward pressure in the concrete practically in the first 2-3 progress cycles. Then the rock pressure (the pressure encountered in mining) becomes the determining force factor. Consequently, with insignificant rock pressure for erecting a pressed cast-in-situ concrete lining it is possible to employ a short pliable (flexible) slip form for 3-4 progress cycles of concreting (2-3 m).

Preliminary investigations have confirmed the operating efficiency of the design of the forms and the merit of the fundamental decisions taken in it. The method of the erection of a tunnel lining from pressed, cast-in-situ concrete is distinguished by a high level of mechan ization of all the production processes and makes it possible to ensure, as a result of its technological peculiarities, the unsettling construction of tunnels under any mining-geological conditions. The employment of slip forms instead of traveling forms will make it possible to increase the rate of construction of tunnels and reduce the work input going into the driving operations by increasing the level of mechanization of the construction.

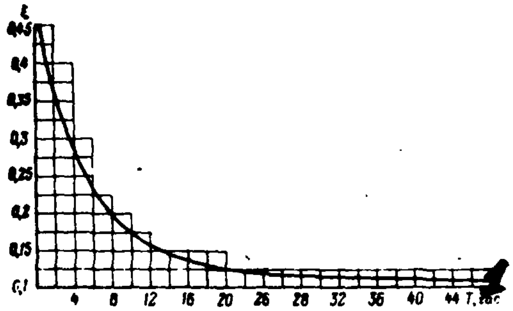

Fig. 3. A graph of the dependence of the coeffici .c f lateral pressure on the age of concrete.
KEY: 1 - hour.

The further experimental-production utilization of forms will make it possible to determine optimum design solutions and the prerequisites for the creation of analogous designs of forms for the construction of large-diameter tunnel linings, including also in rocky regions, where until now large quantities of metal and scarce materials have been expended for temporary supporting.

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